NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4331

AN INVESTIGATION OF THE EFFECTS OF ATMOSPHERIC CORROSION ON THE FATIGUE LIFE OF ALUMINUM ALLOYS

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SUMMARY

Fatigue tests were conducted on 100 vibrating cantilever sheet specimens by applying 4,000 cycles of load in a 10-minute period each working day while the specimens were subjected to atmospheric conditions over a period of several months. Specimens of 2024-T3 and 7075-T6 aluminum alloys in both the bare and clad forms were tested. For comparison, 96 specimens were tested indoors. Atmospheric effects shortened the average lives of the specimens by a factor of about 3 for 7075-T6 and 2024-T3 in the bare condition and by a factor of about 1.5 for 7075-T6 in the clad condition, and had no significant effect on the average life of 2024-T3 clad specimens.

INTRODUCTION

Most of the data used in the design of aircraft are obtained under conditions which, to some extent, prevent serious corrosion. On the other hand, aircraft are exposed to the weather almost continuously for many years during which time dirt, dust, soot, chemical fumes, moisture, salt air, exhaust gases, fuel spillage, and so forth can cause corrosion in many parts. Tests have been performed in order to evaluate the effects of corrosive agents on the fatigue behavior of various metals but these metals are not of the type commonly found in aircraft structures. Furthermore, most of these tests were conducted at an accelerated rate by using corrosive agents such as tap water and acid or salt solutions of various concentrations. The corrosive agents used tend to produce significant effects on fatigue life, but the relation of these effects to those of the atmospheric corrodents mentioned previously has not been established. Therefore, the corrosive influence of the atmosphere on fatigue life of aircraft cannot be evaluated on the basis of existing knowledge.

An investigation has been undertaken to evaluate the corrosive influence of the atmosphere on the fatigue life of aluminum alloys. Tests were conducted under atmospheric conditions prevalent at the Langley

Aeronautical Laboratory which is situated on the Atlantic seacoast. Alternating loads were applied to the specimens for only a short time each working day in order to provide an extended period of time for corrosive action. For practical reasons the test program was arranged to run for several months instead of the many years involved in aircraft. For simplicity, vibrating cantilever sheet specimens were used.

TESTS

Specimens

The specimens were made of 2024-T3 and 7075-T6 aluminum-alloy sheet 0.051-inch thick in both the bare and clad forms. Tensile coupons cut from each sheet of material were tested to obtain the tensile properties listed in table I.

Vibrating cantilever sheet specimens were machined as shown in figure 1. The dashed lines in figure 1, radiating from the point of load application, indicate the shape of a constant stress cantilever. Maximum bending stress occurs in the section at which these lines become tangent to the boundary of the specimen. A 1/4-inch-diameter hole was drilled and reamed in this cross section of each specimen to introduce a stress concentration. The theoretical stress concentration for specimens of this configuration loaded in bending is equal to 1.6 (ref. 1). Edges were carefully machined and burrs were removed with fine emery cloth. Each specimen was measured at the critical section for thickness and net width to 0.0001 of an inch.

Test Apparatus

Corrosion fatigue tests were conducted in a machine (fig. 2) designed to accommodate 100 vibrating cantilever specimens at one time. This machine is located outdoors and positioned so that no shadows are cast on the apparatus except in late afternoon. The principles of its construction and operation are shown schematically in figure 3. This machine consists of a vibrating table supported on coil springs and restricted to vertical motion by a system of flexure arms. The table has a natural frequency of vibration in the vertical direction of approximately 430 cycles per minute and is excited to vibrate at this frequency by an adjustable crank and slipping clutch. The amplitude of vibration is controlled by appropriate adjustment of the crank throw.

The vibration of the machine produces bending stresses in the cantilever specimens which are clamped to the periphery of the vibrating table.

Two adjustable masses are used to obtain the desired stresses in each specimen. The first mass or vibrating mass fixed to the free end of each specimen (fig. 3) adjusts the natural frequency of the specimen to give the desired alternating stress amplitude when the machine is running. The second mass is suspended from the first by a soft coil spring so that the sum of the two masses produces the desired mean stress. The spring is soft enough so that the vibration of the cantilever is not significantly affected by the suspended mass. The suspended mass is submerged in oil (fig. 3) to damp out transient vibrations during starting and stopping. A correction for the bouyant force of the oil is made when the weight of the suspended mass is computed.

The machine is started with the slipping clutch disengaged. When the motor reaches its operating speed, the clutch is engaged slowly until the table vibrates at an amplitude equal to the stroke of the crank. A preset counter is used to stop the machine automatically after a predetermined number of load cycles have been applied to the specimens.

A second machine, which is a scaled-down model of the outdoor machine, was used to test the specimens indoors. This machine had an operating frequency of 575 cycles per minute and could accomodate 8 specimens at a time.

A third machine, a Sonntag SF-2 flexure testing machine, was used to complete portions of some of the tests. Tests in this machine were conducted indoors at 1,800 cycles per minute.

Procedure

The loads to produce the desired stresses in each specimen were computed by the flexure formula, using the measurements taken at the critical section of each specimen. These loads were then applied statically to the specimen to determine the deflection for the desired stress level. These deflections were then used to tune the natural frequency of the specimens to produce the following stresses: 12 ± 25 ksi in bare specimens, 12 ± 14.5 ksi in 7075-T6 clad specimens, and 12 ± 15 ksi in 2024-T3 clad specimens. A mean stress of 12 ksi was chosen to represent 1 g stresses used in current transport airplanes. The alternating stresses were chosen on the basis of a few preliminary tests conducted indoors to produce failure in approximately 5×10^5 cycles.

The specimens were clamped to the vibrating table of the machine on January 31, 1957. The tuning of specimens was hampered because of inclement weather with the result that the machine was operated for the first scheduled run on March 11, 1957. During the tuning operation the amplitude of vibration was measured with a calibrated scale and stroboscopic light. Each specimen was tuned individually while all other specimens were restrained from vibration. An average of approximately 1,000 cycles was applied to each specimen during the tuning operation. The large deflections involved facilitated adjustment to ±1 percent of the desired alternating stress.

Tests were conducted by applying 4,000 cycles of load in a 10-minute period each working day. The mean load was not removed for the duration of the test.

At the beginning of the test series, it was intended that the specimens that failed were to be replaced by other specimens of the same material. However, this procedure became impractical when specimens began failing at a rapid rate. Consequently, only 6 specimens of 7075-T6 bare material were replaced after the program was in progress.

When 500,000 load cycles had been applied to the specimens, the number of load cycles per day was changed from 4,000 to 2,000. At this time only 15 of the 2024-T3 clad specimens remained. These specimens were subjected to 2,000 load cycles per day for 35 days (70,000 cycles) in which time three more had failed. The remaining 12 specimens which all had cracks in them were then removed from the outdoor test apparatus. With the exception of the specimen containing the longest crack, the remaining specimens were tested to final failure indoors at 1,800 cycles per minute in Sonntag SF-2 flexure testing machines. These latter machines were used because tests could be conducted without the tuning required in the machines used for indoor control tests. Such tuning would have produced varying numbers of load cycles of unknown amplitude at a stage of the test where final failure was imminent.

Meteorological data for the duration of these tests were taken from records of the NACA weather station at Langley Field, Va., and are summarized in table II. It rained on almost 50 percent of the days the specimens were exposed, and there was a fairly heavy dew on the specimens practically every morning. Since Langley Field is situated on the Atlantic coast, it is reasonable to assume that the air contained a fair concentration of salt. Thus, the test conditions were probably quite severe compared with average conditions experienced by aircraft.

For comparison, 24 specimens of each of the four materials were tested indoors under the same stresses used in the outdoor tests. Eight specimens were tested simultaneously without interruption.

RESULTS AND DISCUSSION

Specimens began failing 3 weeks after the initiation of the test program. Approximately 6 months later, 500,000 cycles of load had been applied and most of the specimens had failed. The number of cycles of load required to produce failure in each of the specimens are listed in table 3. At the bottom of the table are listed the average lives for both indoor and outdoor tests and the ratio of the average life indoors to the average life outdoors for each material. The data are plotted in the form of probability curves in figures 4 to 7. The results of indoor and outdoor tests for a given material are shown in each figure.

The results of these tests show that atmospheric effects shortened the average lifetimes of the specimens tested outdoors by a factor of about 3 for 7075-T6 and 2024-T3 in the bare condition and by a factor of about 1.5 for 7075-T6 in the clad condition, and had no significant effect on the average life of 2024-T3 clad specimens. The slopes of the probability curves in figures 4 to 7 indicate that the scatter in life of the outdoor tests is consistently less than that in the indoor tests for all materials tested.

Although the mean life of 2024-T3 clad specimens tested outdoors was not significantly different from the mean life of those tested indoors, the scatter in lifetime was about one-half of that found in indoor tests. Thus, the earliest failures in indoor tests occurred in one-half the number of cycles required to produce the earliest failure in outdoor tests. No explanation for this behavior is apparent.

The various changes in test conditions of 2024-T3 clad specimens, discussed previously, had very little effect on the results. The data for these tests lie essentially on a straight-line probability curve (fig. 7). The fact that the data from the tests completed indoors lie on an extension of the curve for results of the first 13 tests completed outdoors is further evidence that corrosion had essentially no effect on the fatigue life of the 2024-T3 clad specimens.

As mentioned previously, six of the 7075-T6 bare specimens were replaced with identical specimens. Those six replacements were tuned and tested immediately after installation while the original 25 specimens were tested approximately 6 weeks after they were mounted on the machine. During most of the 6 weeks the specimens had essentially zero stress. The results in figure 4 show that the long exposure at zero stress was responsible for most of the reduction in life of the original 25 specimens. Obviously, the effect of corrosion during the first 6 weeks of exposure on the fatigue life of specimens of other materials cannot be evaluated from these tests.

Preliminary tests conducted indoors indicated that specimens made of each of the four materials should have mean life expectancies of roughly 5×10^5 cycles. However, additional control tests conducted indoors showed that 2024-T3 clad specimens had the longest lifetimes (approximately 6×10^5 cycles) and 7075-T6 bare specimens had the shortest lifetimes (approximately 3×10^5 cycles). Therefore, in tests conducted outdoors, 2024-T3 clad specimens would have had the longest lifetimes and 7075-T6 bare specimens would have had the shortest lifetimes if no corrosive effects had been present. The following table indicates the approximate ratios of average lifetimes of each test condition as compared with the average lifetime of 2024-T3 clad specimens tested indoors:

Specimen	Stress, ksi	Indoor tests	Outdoor tests
2024-T3 clad	12 ± 15	1.0	0.93
7075-T6 clad	12 ± 14.5	.73	.48
2024-T3 bare	12 ± 25	.79	.25
7075-T6 bare	12 ± 25	.45	.16

Thus, the greatest reduction in average life due to atmospheric exposure was experienced by 2024-T3 and 7075-T6 bare specimens even though they had the shortest exposure times of all the specimens tested outdoors. Presumably these materials would have experienced a greater reduction in lifetime if their exposure times had more nearly matched that of the 2024-T3 clad material. On the other hand, lifetimes of 2024-T3 clad specimens showed the least effect of atmospheric exposure in spite of the fact that the exposure time was the longest. Thus, the foregoing table probably ranks the materials in the correct order of their resistance to loss of fatigue life due to atmospheric corrosion.

A fairly high mean stress was applied continuously and alternating stresses were high to produce failures in a reasonably small number of load cycles. On the other hand, exposure to the atmosphere was limited to less than 6 months in most specimens. Conceivably, corrosion effects could be more deleterious if exposure times were increased.

CONCLUDING REMARKS

Corrosion fatigue tests were conducted outdoors on 2024-T3 and 7075-T6 aluminum-alloy specimens in both the bare and clad forms. Twenty-five specimens were tested at one stress level for each material. The cyclic loads were applied to the specimens 4,000 times in a 10-minute period each working day. The mean load was applied continuously for the duration of the test. For comparison, 24 specimens of each material were tested indoors. From the data presented, the following tentative conclusions seem to be justified:

1. The fatigue lifetimes of all the materials tested, except 2024-T3 clad, were significantly reduced by atmospheric corrosion.

2. The bare materials experienced a greater decrease in life due to atmospheric corrosion than did clad materials.

3. Exposure to atmospheric corrosion for 6 weeks at zero stress apparently had a more significant effect on the life of 7075-T6 bare specimens than did corrosion which took place during fatigue testing.

4. Scatter in life of indoor tests was greater than in outdoor tests.

Additional data are required to evaluate adequately the effects of atmospheric corrosion on fatigue behavior. In particular, the test conditions should be varied to produce much longer exposure times. Tests at other stress levels would also be of interest.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 14, 1958.

REFERENCE

1. Peterson, R. E.: Stress Concentration Design Factors. John Wiley & Sons, Inc., c.1953.

TABLE I

TENSILE PROPERTIES OF MATERIALS TESTED

Material	Yield stress (0.2 percent offset), ksi	Ultimate strength, ksi	Total elongation 2-inch gage length, percent	Young's modulus, ksi	Number of specimens
2024-T3 bare	55.8	72.3	16.5	10.53×10^3	5
2024-T3 clad	50.7	66.7	16.0	9.51	3
7075-T6 bare	79.3	85.9	11.3	10.36	3
7075-T6 clad	66.6	73.8	10.9	9.71	4

TABLE II

AVERAGE METEOROLOGICAL DATA FOR TEST PERIOD

Month	Precipitation, in.	Number of days of precipitation	Average relative humidity at 7:00 a.m., percent
February	4.39	22	81
March	5.34	20	80
April	3.01	13	75
May	1.38	8	73
June	2.27	16	75
July	1.66	8	67
August	6.15	11	76
September	4.59	14	81
October	2.96	12	80
November	4.89	15	83

TABLE III

FINAL LIFETIMES OF INDIVIDUAL SPECIMENS[a]

	2024-T3 bare at stress of 12 ± 25 ksi		2024-T3 clad at stress of 12 ± 15 ksi		7075-T6 bare at stress of 12 ± 25 ksi		7075-T6 clad at stress of 12 ± 14.5 ksi	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
	212,200	112,700	227,000	417,800	98,000	64,000	277,000	212,200
	220,200	113,900	311,800	442,500	116,300	64,600	303,600	234,800
	232,700	115,600	332,200	451,200	125,000	66,900	311,800	249,500
	234,100	119,000	337,500	457,200	144,300	67,500	321,500	253,300
	247,000	125,700	339,400	464,200	144,700	80,100	322,800	256,900
	251,400	126,400	372,200	477,800	148,000	84,400	332,200	259,400
	276,400	139,700	405,800	480,000	153,500	86,800	337,500	260,400
	280,300	140,700	452,300	486,000	155,100	87,000	339,400	260,900
	285,800	141,300	509,900	494,900	159,500	88,700	355,000	265,500
	311,900	141,800	534,100	495,900	170,800	90,100	364,000	265,600
	350,500	143,300	535,000	[b]507,300	171,600	91,500	372,200	266,400
	368,700	146,300	537,200	[b]567,000	176,300	91,700	384,600	268,200
	375,800	149,500	547,200	[b]569,700	182,200	93,400	396,300	269,800
	410,000	149,700	649,300	(c)	187,100	93,900	405,800	272,600
	455,700	152,500	657,700	[d]588,000	189,000	94,000	430,900	279,700
	469,700	153,100	707,800	[d]595,000	201,900	94,200	431,000	279,900
	477,700	153,900	808,600	[d]596,000	202,500	95,900	439,600	286,300
	505,100	156,800	863,000	[d]598,000	215,300	97,500	505,500	292,000
	525,500	162,300	865,000	[d]604,000	222,500	98,000	518,700	299,500
	594,600	163,700	913,700	[d]615,000	255,100	98,200	519,900	319,900
	650,400	183,700	993,800	[d]627,000	328,400	98,600	547,200	324,600
	671,500	165,100	1,045,300	[d]632,000	481,500	100,000	579,200	327,800
	1,107,700	165,500		[d]662,000	847,900	102,000	643,100	329,100
	1,624,600	165,800		[d]671,000	1,568,800	[e]107,400	887,400	364,800
		184,500		[d]721,000		116,100		367,300
						[e]124,700		
						[e]144,800		
						[e]153,000		
						155,700		
						[e]190,400		
						[e]216,300		
Average lifetime	464,100	146,100	590,600	[f]550,900	276,900	[g]92,000	430,300	282,600
Ratio of lifetimes	3.18		1.07		3.01		1.52	

[a]Unless otherwise noted, outdoor tests were conducted at 4,000 cpd and indoor tests were uninterrupted.

[b]Tested outside 500,000 cycles at 4,000 cpd; balance at 2,000 cpd.

[c]Tested outside 500,000 cycles at 4,000 cpd and then tested outside 70,000 cycles at 2,000 cpd. This specimen had the longest crack of 12 remaining specimens. This specimen was not tested to failure and was assumed to have failed before remaining 11.

[d]Tested outside 500,000 cycles at 4,000 cpd and then tested outside 70,000 cycles at 2,000 cpd; and balance inside.

[e]Replacements of first six specimens failed.

[f]Average of 24 lifetimes regardless of test condition.

[g]Average does not include replacements.

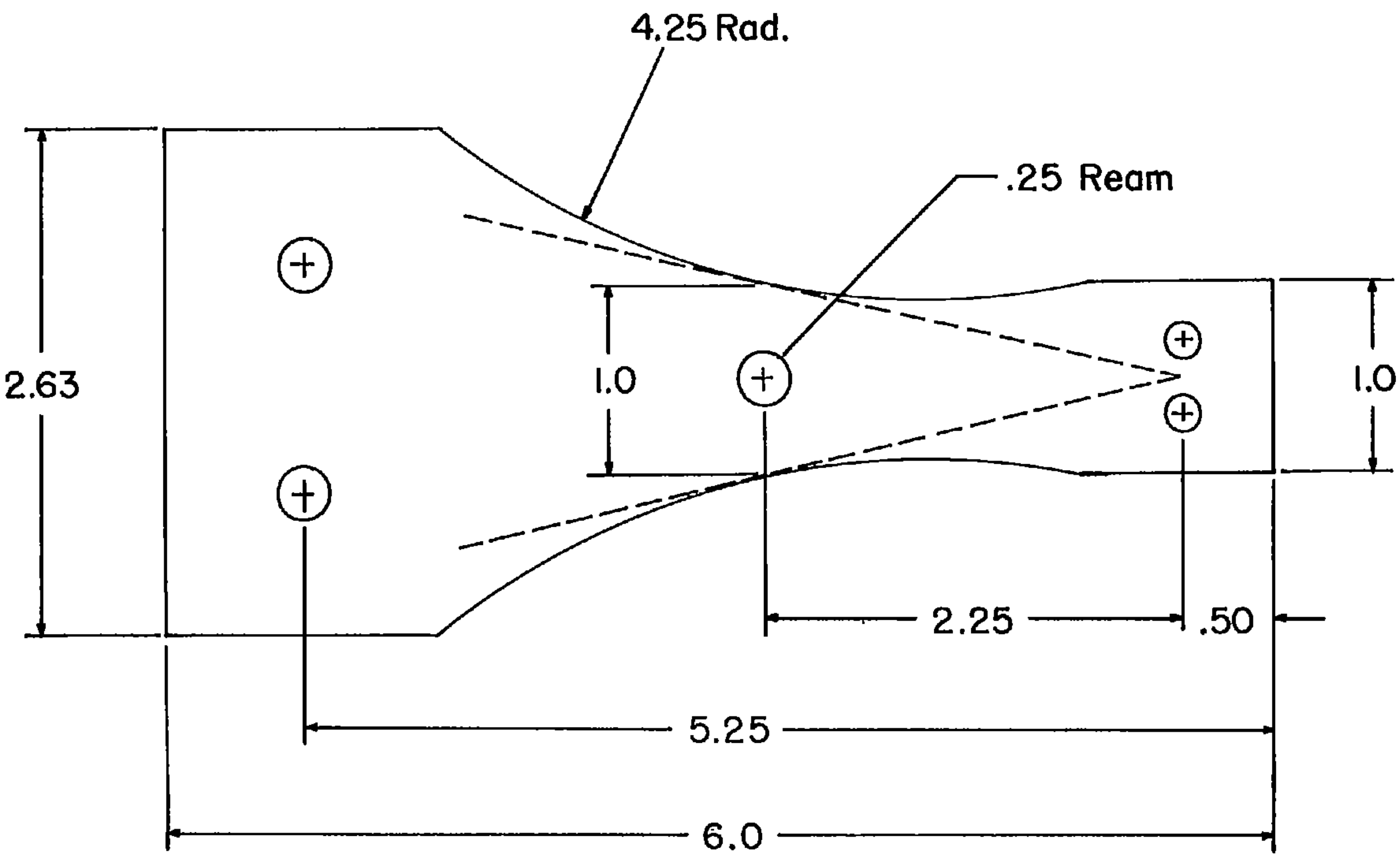

Figure 1.- Specimen configuration. All dimensions are in inches.

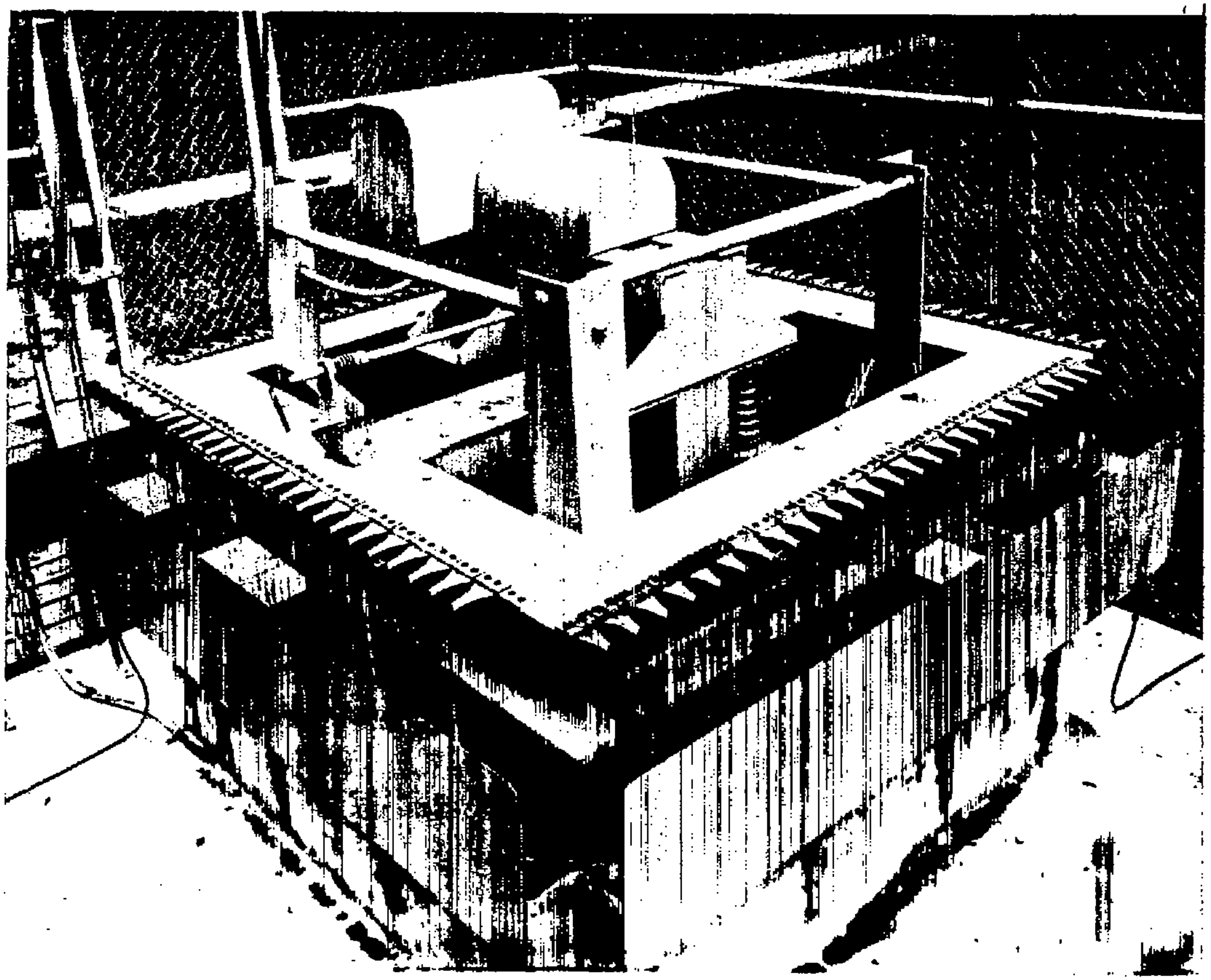

Figure 2.- Corrosion fatigue testing machine. L-57-4264

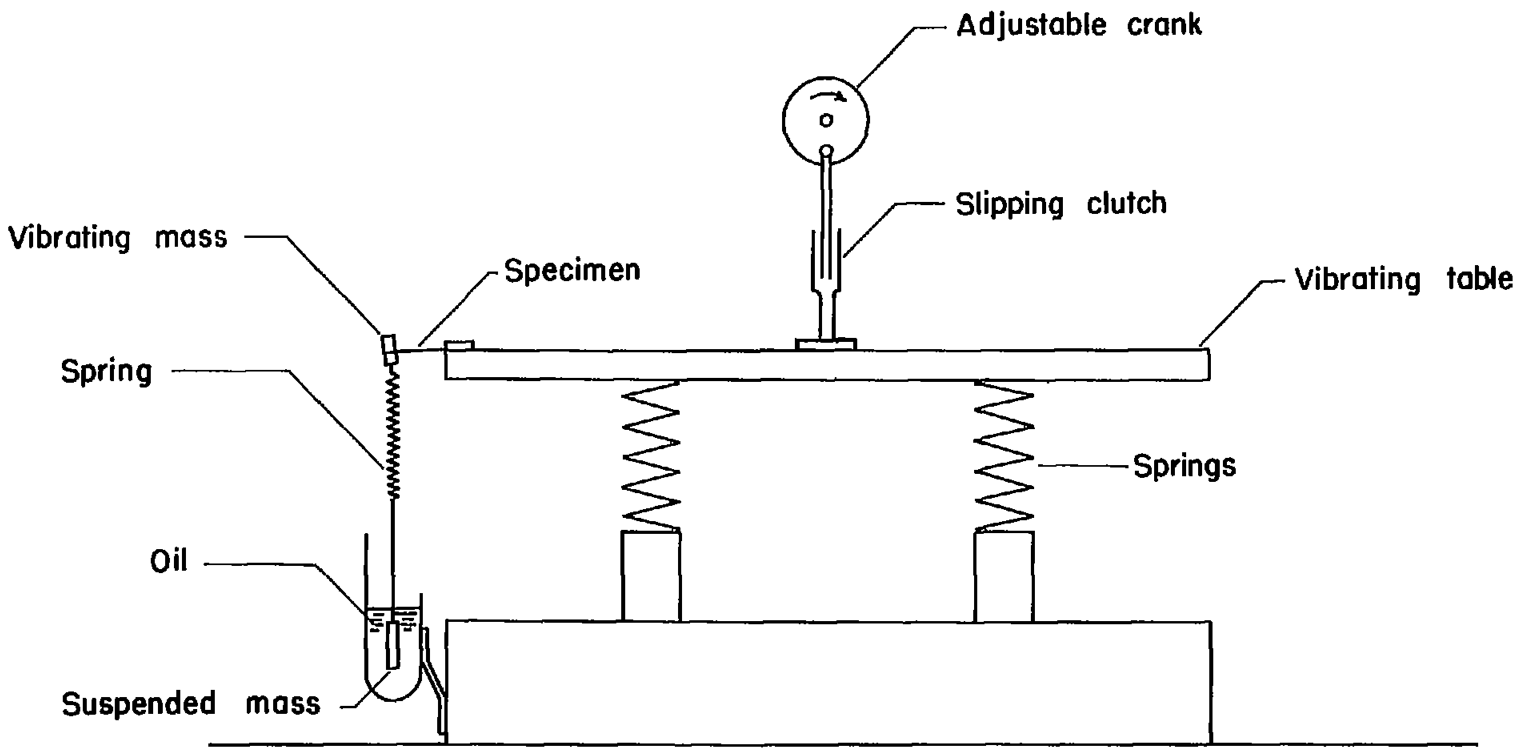

Figure 3.- Schematic of corrosion fatigue testing machine.

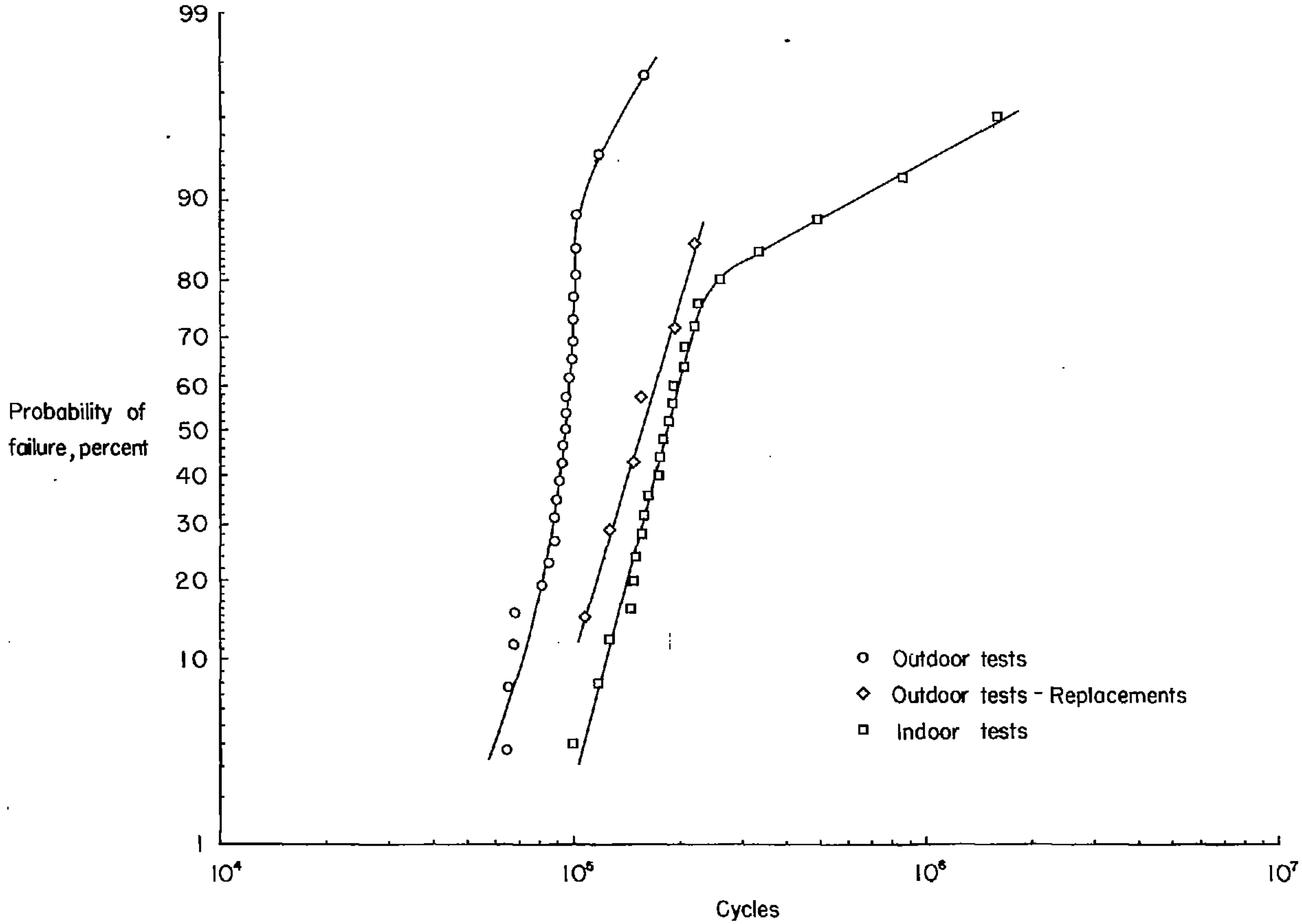

Figure 4.- Probability of failure in specimens made of 7075-T6 bare aluminum alloy.

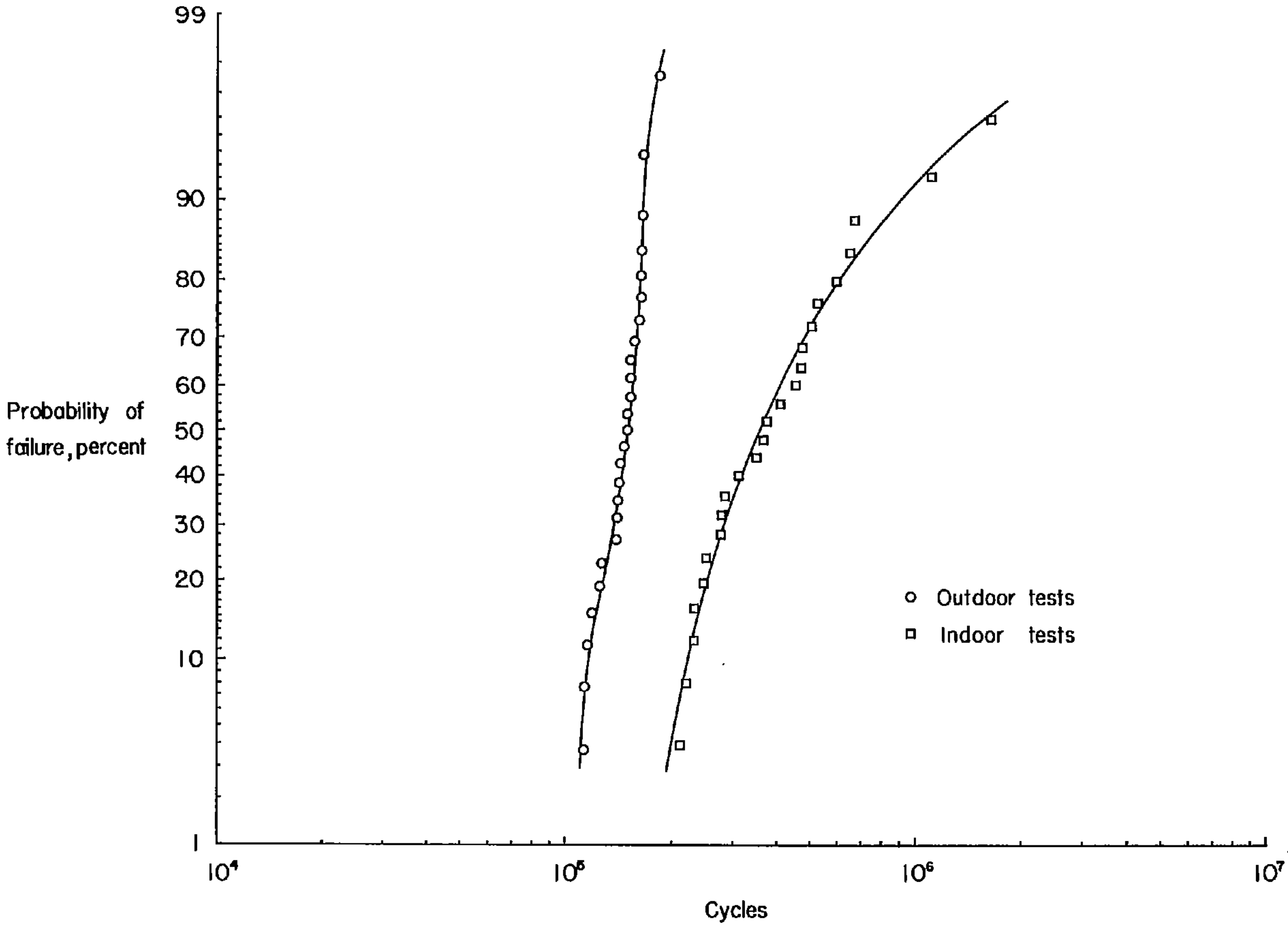

Figure 5.- Probability of failure in specimens made of 2024-T3 bare aluminum alloy.

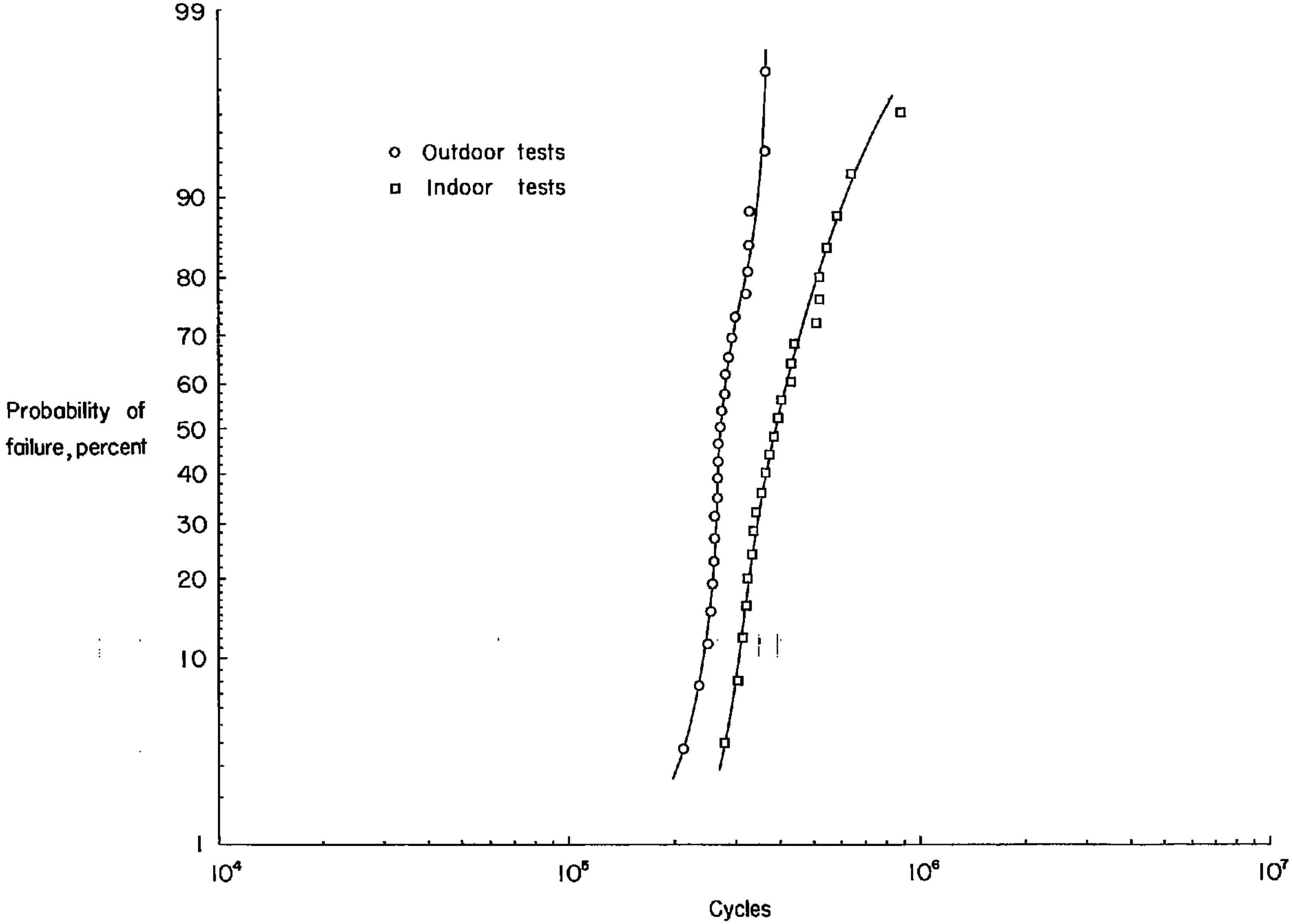

Figure 6.- Probability of failure in specimens made of 7075-T6 clad aluminum alloy.

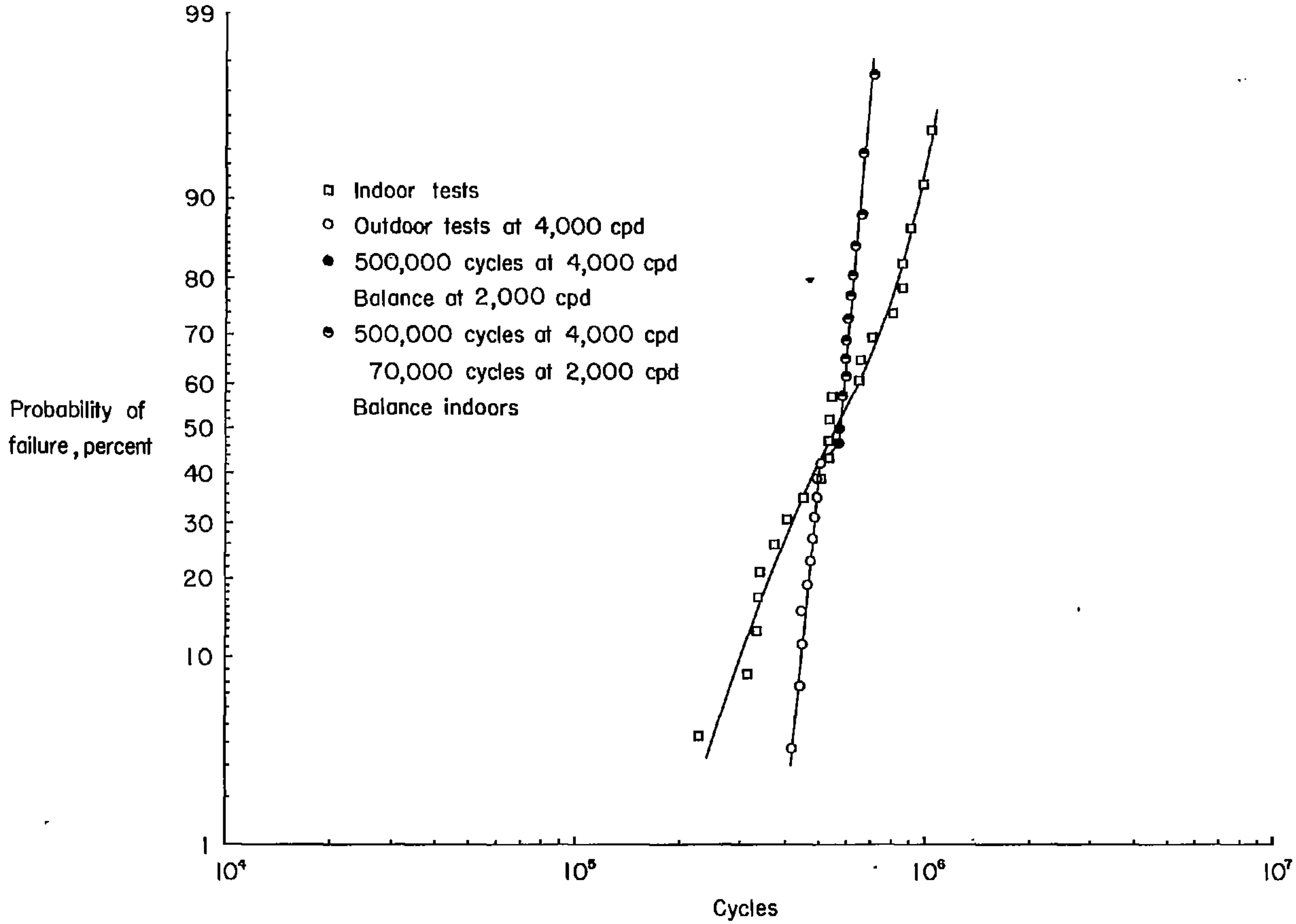

Figure 7.- Probability of failure in specimens made of 2024-T3 clad aluminum alloy.